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16. ABSTRACT

This paper reviews the results of fine particulate control technology tests by the Particulate Technology Branch (PATB) of EPA's IERL-RTP over the last 3 years. The review covers characterization of conventional control equipment, assessment of the collectability of dusts, and new idea evaluation and identification. Results from electrostatic precipitator (ESP) tests show that they can control the removal of particles smaller than 2 micrometers better than was previously thought. ESP field charging does not reach its minimum until well below the 1.0 micron size. Scrubbers show a dramatic decrease in efficiency aw the particle size drops. The most efficient scrubbers also require the most energy. Fabric filters, although limited in control abilities by the filter media, show satisfactory effectiveness in the control of fine particles. Even though only four novel devices are now under consideration by IERL-RTP, testing on them proved successful, and the future appears promising for their control of all emitted particulate matter.

micrometer

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Dust--	Stationary Sources	11G
Aerosols	Particulate	07D
Electrostatic Precipitators	Fabric Filters	13I
Scrubbers	Novel Devices	07A
Fabrics		11E
Filtration		

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Figure 1. Measured efficiency as a function of particle size for precipitators.

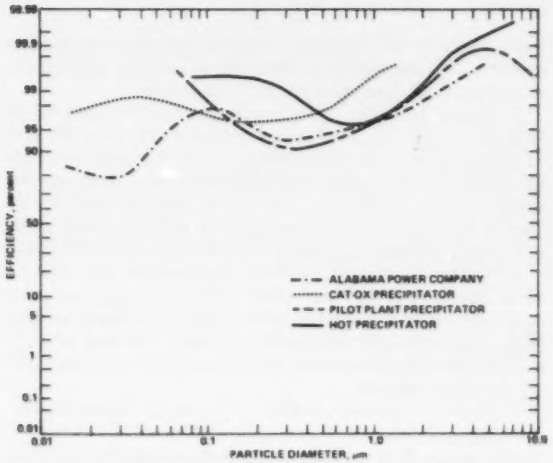

Table 1. Results of field tests on electrostatic precipitators.

Source	Type ESP	SCA sq. ft./1,000 actual cu. ft./min.	Temperature, °F	Efficiencies, % Particle Diameter: Overall	2 micron	1 micron	0.5 micron	0.1 micron	Comments
Coal-Fired Boiler	Cold Side	283	300	99.6	98.9	97	95	98	Moderate Sulfur Coal
Coal-Fired Boiler	Cold Side	238	315	99.8	99.9	99.6	99	99	High Sulfur Coal No Impactor Data
Coal-Fired Boiler	Cold Side	340	320	98.3	99	96	80	98	Low Sulfur Coal
Coal-Fired Boiler	Hot Side	450	700	99+	99.6	97	95	99.3	Tests Completed Data Not Reported

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JOURNAL ARTICLE

EMISSION CONTROL:

Control of Fine Particulate Emissions

More work is needed to improve the efficiency of electrostatic precipitators in removing particulates 0.1 to 1 micron in size, the material that causes atmospheric haze.

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The Environmental Protection Agency's Industrial Environmental Research Laboratory in North Carolina (IERL-RTP) has responsibility under the Clean Air Act of 1970 for the development and demonstration of control technology for air pollutants emitted from stationary sources. One of the pollutants among the six frequently referred to as criteria pollutants is particulate matter. It is the responsibility of the Particulate Technology Branch (PATB) of IERL-RTP to develop and demonstrate, on a pilot scale, control technology that is generally applicable to particulate and fine particulate matter emitted from all stationary sources. (Technically, fine particulates are those less than 2 to 3 microns in diameter, although for practical purposes the lower limit diameter of such matter is now set at 0.01 micron.)

For the past three years PATB has been engaged in a program aimed at determining the limitations of conventional particulate control devices and a defining a research and development effort that will eventually produce the needed technology for the control of fine particulates. In addition, IERL-RTP has established a program, outline below, to develop control technology for fine particulates:

1. *Measurement.* The principal goals of this effort are 1) to select, calibrate and standardize measurement equipment and procedures to be used in support of the entire

particulate control program, and 2) to develop instruments capable of determining efficiencies of control equipment on particle size fractions on a real time basis.

2. *Characterization of conventional control equipment and assessment of the collectability of dusts.* It is the aim of this program area 1) to ascertain, on the best available conventional equipment operating on real sources, the actual control capability in terms of size fractional efficiency, 2) to develop a data base for decisions and judgments with respect to the capability of commercially available control equipment, and 3) to determine the ease or difficulty with which any given industrial dust pollutant may be collected. With this information it should be possible to predict with reasonable accuracy the ease or difficulty of, and the system required for, control of almost any particulate problem.

3. *New particulate control technology development.* The goals for this area are 1) assess all potential collection mechanisms, 2) to initiate exploratory projects to evaluate feasibility of concepts and/or mechanisms, and 3) to develop pilot units for promising systems.

4. *New idea evaluation and identification.* The goals of this program area are 1) to evaluate novel devices, 2) to generate a plan to solicit, stimulate, and identify new ideas and concepts for fine particulate control, and 3) to carry out a pilot-scale demonstration of the most promising devices.

5. *Accelerated pilot demonstrations.* Work in this area will be dedicated to the early pilot demonstration of candidate fine particle control equipment for real world problems.

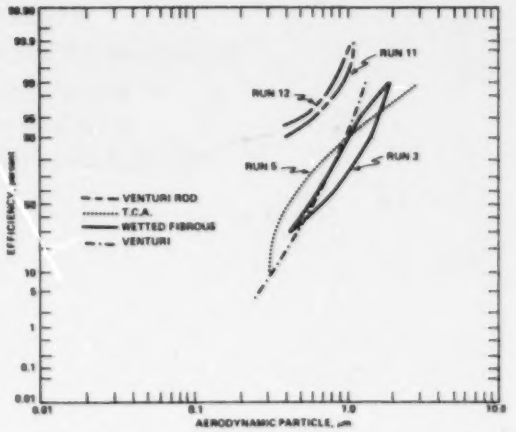

Figure 2. Fractional efficiency vs. aerodynamic diameter for scrubbers.

Table 2. Results of field tests on scrubbers.

Source	Scrubber Type	Average Pressure Drop, in H_2O	Temperature, °F	Efficiencies, % Particle Diameter				
				Overall	0.3 micron	0.5 micron	1 micron	2 micron
Coal-Fired Boiler	Chemico Venturi (360,000 actual cu. ft./min.	10	325	Not Measured	7	47	90	99+
Coal-Fired Boiler	UOP TCA (400,000 actual cu. ft./min.)	12	290	Not Measured	10	70	90	98
Iron-Melting Cupola	National Dust Collector Venturi-Rod (45,000 actual cu.ft./min.)	107	190	Not Measured	—	9.3-97	98.6-99.6	99.9+
Salt Dryer	Encont Corp. Wetted Fiber (60,000 actual cu. ft./min.)	7.5	100	Not Measured	—	0.56	79	99

Control equipment performance

From the remarks above it is clear that the state-of-the-art performance review to be presented here will be based largely on data collected from program areas 2 and 4 described earlier. The tests PATB has been conducting during the last three years on electrostatic precipitators, scrubbers, and baghouses have employed a complicated measurement technique to collect fractional efficiency data that involved the use of inertial impactors, optical counters, condensation nuclei counters, and diffusion batteries. (*1*) In some instances the results are based in impactor data alone, but for the most part several of these devices were used during these tests, which were conducted so that removal efficiencies on different particle fractions could be obtained down to about 0.01 microns. In most cases, overall efficiencies were calculated from standard EPA Method 5 measurements taken on both the inlet and outlet control device. (*2*) The basic product of all these tests was a graphical representation of removal efficiency vs. particle diameter for each control device.

Results of the performance tests conducted by IERL-RTP on electrostatic precipitators on coal-fired utility

boilers and on an industrial emitter of fine particulates are shown in Figure 1. (*3*) It was conclusively revealed during these studies that industrial-scale precipitators have considerable potential as fine particle control devices. Prior to the disclosure of these results it was widely believed that the removal efficiency of an electrostatic device would drop rapidly for particles below about 2 microns in size. This is the size at which the main particle charging mechanism called "field charging" begins to become ineffective. These results indicated that, even in the submicron range, significant collection, and thus particle charging, occurs. The charging process, which comes into significance on these very small particles, is termed "diffusion charging." Important process and equipment parameters for this test are shown in Table 1.

Other curves in Figure 1 represent tests conducted on additional electrostatic precipitators. (*4*) It is interesting to note that in all cases a clear minimum in the efficiency curve occurs in the particle diameter region of 0.1 to 1.0 microns, and is close to the midpoint of this range. This observed minimum is probably caused by the changing particle charging rates from both the diffusion and field charging mechanisms. This particle size range represents a transition region where particles begin to exhibit actions

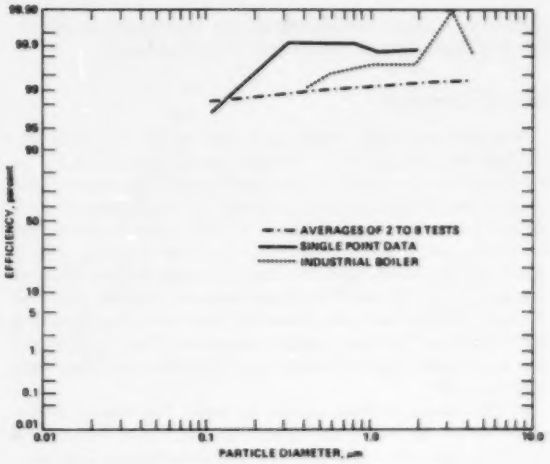

Figure 3. Baghouse performance on utility boilers.

Table 3. Collection efficiency of fabric filter systems.*

Boiler Type	Overall Mass Average Efficiency, %	Air-to-Cloth Ratio	Efficiency at Approximate Particle Diameter, %					Filter Fabric & Cleaning Type
			4 micron	2 micron	1 micron	0.5 micron	<0.3 micron	
Pulverized**	99.8 (including mechanicals)	2.0:1	—	99.7	99.7	99.8	94.5	Glass/Teflon Reverse Air
Coker; Slip Stream from Stack	99.8	~3:1	99.6	99.6	99.4	99.2	99.9	Nomex Reverse Air
Coker†	99.9	~4.1:1	99.3	99.3	98.3	98.9	98+	Glass/Graphite Repressure Air Plus Shake

*Data from preliminary tests; need to be confirmed by further testing.
**Data calculated for worst case. Outlet loading +0.024 gr./daily std.cu.ft.
†Outlet loading = 0.004 gr./std.cu.ft.

characteristic of gases. Diffusion charging is related to the motion of negative ions in the gas stream due to their thermal velocity (Brownian motion), and field charging is due to the flow of negative ions along the direction of the electric field. Table 1 summarizes the results of these tests along with important precipitator and process parameters.

The EPA Research Laboratory has tested scrubbers of conventional design on a variety of particulate sources. Curves in Figure 2 represent a graphical summary of some of the data from four different scrubbers. (*5*) In general, the efficiency of a scrubber drops off rather rapidly as the particle size decreases. It can also be said that the efficiency is directly related to the energy consumed by the scrubber. This can be seen by comparing the venturi with Runs 11 and 12. The first represents the performance of a venturi scrubber operating on a pressure differential of about 10 in. H_2O and Runs 11 and 12 represent a venturi-rod scrubber operating on a pressure differential of 107 in. H_2O and (even though somewhat different in mechanical design) is much more efficient at all particle sizes than is the conventional venturi. At a particle diameter of 1 micron, for example, the efficiencies are 90 vs. 99.9%, a difference in penetration of about two orders of magnitude.

Table 2 summarizes the test conditions and results along with some scrubber and process parameters. All four scrubber types tested and reported here are of conventional design and depend largely on impaction between water drops and particles as the major collection mechanism.

Curves in Figure 3 represent fractional size efficiency data obtained from tests performed on baghouses operating on both utility and industrial boilers. (*6, 7*) As can be seen from the figure and from Table 3, which presents a summary of the results along with some important equipment and process parameters, baghouses are very efficient particulate control devices. In a general way the overall efficiency of a baghouse is a function of fabric type, bag condition, cleaning method, and cleaning cycle. The bag

condition is highly dependent on the care given to operation and maintenance of any individual baghouse.

Novel devices

Over the past two years, as a part of an effort to encourage the development of new devices that might be applicable to fine particulate control, the Research Laboratory has considered the potential of approximately 40 different novel devices. Of these, 10 have been tested either in the laboratory or on actual sources, and tests are scheduled or planned on more for the very near future. Most of the devices tested thus far have been scrubbers with one or more unique features. One test was on a device using sonic energy to promote agglomeration of the fine particulate, a unit that might be best described as a scrubber with a sonic assist.

Of the novel devices tested to date, the steam hydro scrubber produced by the Lone Star Steel Co., stands out from the rest with respect to its performance on fine particulates. This unit is a high energy user that will find applications on processes having waste heat in an off-gas stream containing particulates. The waste heat is used to generate steam, which is then injected under high pressure into the throat of an aspirating type venturi. Because of the high energy consumption of this equipment its applica-

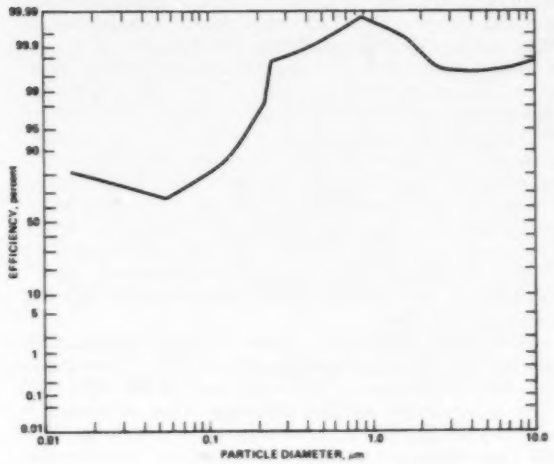

Figure 4. Fractional efficiency of the Lone Star steam hydro scrubbers.

Table 4. Novel device collection efficiency.

Lone Star Scrubber		Dynactor Scrubber		ADTEC Scrubber			J-M CHEAF**		Entoleter Scrubber	
				% Eff.					% Eff.	
micron	% Eff. (P)*	micron	% Eff. (A)	micron	(P)	(A)	micron	% Eff. (A)	micron	(P) (A)
—	—	—	—	10.0	99.3	99.2	—	—	10	99.85 99.8
5.0	99.6	4–5.6	99.0	5.0	99.4	99	5.0	94.2	5	99.7 99.3
3.25	99.7	2.5–4	98.4	—	—	—	3.0	94.8	3	99.1 98.5
2.0	99.85	1.3–2.5	93.0	2.0	99.0	99.1	2.0	94.6	2	98.5 95.5
1.0	99.99	0.8–1.3	75.4	1.0	99	98.3	1.0	93.9	1	90 73
0.5	99.9	0.54–0.80	27.4	0.5	99	93	0.5	93.0	0.5	50 —
—	—	<0.54	47.4	—	—	—	—	—	—	— —
0.25	99.8	—	—	0.25	92	91	0.25	93.7	0.25	30 —
0.1	85	—	—	0.1	35	—	—	—	0.1	20 —
0.05	70	—	—	0.05	35	—	—	—	0.05	50 —
0.01	90	—	—	0.01	70	—	—	—	0.01	90 —
Total Mass (Avg.)	99.9	—	93.1	—	95.9	—	—	95	—	99.6 —
Mass (Range)	99.84–99.9	—	81.8–96.4	—	95.1–96.7	—	—	92–96	—	99.4–99.8 —

Pentapure		Rexnord Gravel Bed		APS Electrostatic Scrubber		CHEAF†	
micron	% Eff (A)	micron	% Eff (A)	micron	% Eff (A)	micron	% Eff (A)
5	—	5	97.5	5	99+	5	93.4
3	44	—	—	3	98.4	3	97.4
2	40	2	30	2	96	2	97.8
1	10	1	0	1	91	1	97.1
0.5	0	—	—	0.5	93	0.5	90.4
—	—	—	—	0.25	82	0.25	78
—	—	—	—	0.1	87	0.1	45
Total Mass (Avg.)	10.0	—	96.5	—	91.5	—	94.6
Mass (Range)	8.0 → 12.8	—	95.0 → 98.0	—	83.2 → 96.9	—	94.1 → 95

*(P) = physical diameter; (A) = aerodynamic diameter
**Field test
†Lab test

tion may be somewhat limited; however, as can be seen from Figure 4 it is a very efficient and effective particulate control device with an overall mass efficiency of 99.9% on a source (open hearth steel furnace), which contained a large portion of particulate in the size range below 1 micron. Figure 4 shows that efficiency of this scrubber system was greater than 90% for all particulate size fractions above about 0.2 microns.

Other novel devices which have shown acceptable performance on fine particle collection are the CHEAF filter, ADTEC scrubber, and A.P.S. electrostatic scrubber. A summary of results obtained from eight of the devices tested is shown in Table 4.

When a concept for fine particle control does not rely solely on mechanisms found in a scrubber, a fabric filter, or an electrostatic precipitator, it is considered for development as a new concept. Projects of this type that have been initiated are:

1. Charged droplet scrubber (TRW).
2. Electric curtain (Univ. of Illinois).
3. Electrostatic fiber beds (Battelle-Northwest).
4. Foam Scrubbing (Monsanto Research Corp.).
5. Cleanable double media cartridge filtration (Donaldson).
6. Electrostatic effects in fabric filtration (Carnegie-Mellon).
7. High gradient magnetic separation (Research Triangle Institute).
8. Ceramic membrane filtration (Westinghouse).

Most concepts are at an early stage of development, and only the charged droplet scrubber has been tested at demonstration scale. This test was conducted on the combustion gases of the coking battery at the Kaiser Steel plant, Fontana, Calif. Total mass removal efficiencies were as high as 94.4%, and the particles inlet to the scrubber had approximately a 0.6 micron mass median diameter. Hence, this new concept has been demonstrated to be an efficient fine particle collector.

In conclusion

From the data presented here it can be concluded that adequate control of emitted submicron particulate matter is presently possible, but not broadly applicable to a wide variety of sources.

Highly efficient electrostatic precipitators installed on sources whose dust properties are such that they lend themselves to electrostatic collection can currently be effective in controlling fine particles. Additional research and development is needed, however, to improve the performance of precipitators on particulate in the size range of 0.1 to 1 microns. This size range is quite important since it is the most optically active and causes atmospheric haze and thus visibility problems. Techniques that either enhance charging or selectively charge fine particles are currently being sought by programs of the Industrial Environmental Research Laboratory.

Conventional scrubbers are not very efficient collectors of fine particles. Current research and development efforts to improve scrubbers are directed toward more efficient utilization of the energy applied to a scrubber system, and toward taking increased advantage of condensation and other physical phenomena that affect, to some degree, the performance of all scrubbers.

Fabric filters, insofar as current test data show, are quite effective collectors of fine particles. Their use is currently limited by the physical properties of the filter media and by the large size of the required container. More mechanically durable, as well as chemical and heat resistant filters, are needed. In addition, filters must be developed that can be used at air-to-cloth ratios 10 to 100 times greater than is the current practice. An increase in the allowable level of this parameter will result in a direct reduction in container size.

So far, only four novel devices have been tested and found to be good collectors of fine particulate. Many more tests are planned on these units, and a number of new and different concepts, such as electrostatic fabric filters, high gradient magnetic separators and foam scrubbers are being investigated. It is hoped that several of the devices and concepts currently under consideration by the Research Laboratory will ultimately result in the demonstration of new and economically attractive processes for the control of all emitted particulate matter.

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